An approach for study wood supply from Acacia seyal stands on Gadaref State, A case study: Wad Elkheseid natural forest reserve

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Dedication

To my father, mother, brothers
and sisters

Acknowledgement

I would like to express my deep gratitude and sincere appreciation to my supervisor Dr. Abdalla Mirghani Eltayb, for his continuous valuable guidance , advice, encouragement, follow up and supervision over the whole period of the stndy.

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Abstract

An approach for sustainable managmement of Acaia seyal natural forest, Acase study: Wad Elkhesheid natural forest reserve

The general argument for natural forest management for timber is that, by conferring relatively more economic value on forests than alternative forest uses. Natural forest management for timber is necessary, though imperfect, means by which extensive areas of forest cover and a large measure of their biological diversity would be maintained outside nature reserve.

This research is an attempt to design a model for managing natural forests on sustainable basis (taking Wad Elkhesheid Forest as a smple).

Research method applied is an enumeration method based on measueable parameters (height, diameter at breast height and form factor) for investigating the relationship between diameter and height, and consequently determining the volume.

.The relationship between height (dependent variable) and diameter at breast height (independent variable) of Talih trees was statistically significant at ($P < 0.0001$) for the equation:

$h = 3.3526 + 0.2913$ dbh ($r^2 = 0.66$ %), where; h = average height and dbh = diameter at breast height.

The form factor of Talih trees growing in the study area showed a great variation ranging between 0.22 % to 0.68 %. Therefore, the form factor was used as a parameter for establishing relationship with height and diameter at breast height.

The relatively low coefficient of variation in height of Talih trees (35.11) indicates that there is rather high degree of homogeneity in height. The big coefficient of variation in basal area (100%) and volume (169%) can be attributed to the big variation of tree diameters and this can be accepted as long as our forest is natural one.

The Average number of natural regeneration of Talih trees per feddan in the study area is 20.23.

The mean annual increament for Talih diameter in the area is 0.77 cm / year.

The diameter distribution of Talih trees in the study area indicates that the sustainable production of firewood from Talih trees is possible if the study area is put under management following selective felling system.

It is recommended to manage the natural forests on sustainable basis depending on the adoption of selective felling.

ملخص الأطروحة

يهدف هذا البحث لوضع وزج لادارة الغابات الطبيعية على اسس مستدامة .

اتبعت عدة طرق مع المعلومات اصة بالدراسة، حيث لت المعاينة تانظامية بـنء على 5 %

نيبة عينات نطقة الدراسة، والقياسات الدقيقة للارتفاع، القطر عند مستوى الـصدر ومعامـل الشكل لشجرة الطلح دف ديد العلاقة بـ الارتفاع والقطر عند مستوى الـصدر وبالتـا جم.

أوضحت نتائج الدراسة أن العلاقة بـ الارتفاع (ا تغ التابع) والقطر عند مـستوى الصدر (ا تغ ستقل) لاشجار الطلح إحصائيا ذو فروق معنوية عند (0.0001) >P عند r^2 = 66 % للمعادلة التالية :

$h = 3.3526+ 0.2913$ dbh ، حيث: h = الارتفاع و dbh = القطر عند مستوى الصدر.

اوضحت الدراسة ان معامل الشكل لشجرة الطلح ا زروع منطقة الدراسة اظهـر تغ ا يتراوح بـ 0.22 – 0.68 لذلك فقد استعمل معامل الشكل لتاسيس علاقة مع الارتفاع والقطر عند مستوى الصدر.

الا فاض قيمة r^2 بالنسبة للارتفاع (35.11) يوضـح أن هنالـك ـانس الارتفاع. لذلك فان التغ الكب قيمة ساحة القاعدية وا جم كن أن ينسبا إ التبـاين الكب قطر الأشجار والذى كن أن يكون مقبولا حالة الغابات الطبيعية.

اوضحت الدراسة ان معدل الانبات الطبيعى لشجرة الطلح يساوى 20 نبته الفدان.

أثبتت الدراسة أن معدل الزيادة السنوية لاشجار الطلح منطقة الدراسـة يـساوى 77,سم / السنة .

توزيع أقطار الأشجار بالنسبة للطلح منطقة الدراسة يدل على أن امكانيـة الإنتـاج ا ستدام من حطب الوقود من أشجار الطلح كنا لو اديرت منطقة الدراسة على اساس نظـام القطع الاختياري.

أوصت الدراسة بإدارة الغابات الطبيعية على أساس الاستمرارية باتباع نظـام القطـع الاختيارى.

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CHAPTER ONE
INTRODUCTION

The general argument for natural forest management (NFM) for timber is that, by conferring relatively more economic value on forests than alternative forest uses. NFM for timber is a necessary, though imperfect, means by which extensive areas of forest cover and a large measure of their biological diversity would be maintained outside nature reserve. Both proponents and critics of NFM for timber can be carried out in ways that mitigate the negative effects on biological diversity, and second, there is a common set of conditions necessary to maintain forest cover for any use, including NFM for timber or nature reserves (Dickinson, Dickinson and Putz, 1996). Johnson and Sarre (1995) reported that forest management can be an instrument of conservation if prices for forest products are high enough to ensure that the annual revenue they generate is greater than that of alternative land uses over the same time span if such revenues are used to secure and sustain the resource. Ladrach and Wright (1995) stated that a major obstacle to successful implementation of the management plan is the lack of effective control of illicit felling in both the natural regeneration and primary forest within the concession.

FAO (1993) stated that in the natural broad-leaved forest, logging role provides for a minimum diameter but are incomplete: logging is not monitored to safeguard the younger trees, minimum logging diameters seem not to have been rationally defined in view of establishing a regeneration cycle, and it doesn't appear that a sufficient number of high grade saplings are left after felling. In the natural pine forest, polycyclic felling at minimum diameter is inappropriate because the species are light demanding. Here clear felling would be better, provided nurseries and fires are effectively controlled to encourage regeneration.

Vanclay, Sayer and Byron (1997) asked what will decide the management of the remaining natural forest in the 21st century. The reply is that in the past, forecast of future timber needs have been an important consideration in determining the extent of national permanent Forest State. If timber is increasingly to come from plantations, one might expect that this would lead to a reappraisal of such policies, and to a reduction in the area of natural forests. However few countries have responded in this way. Rather the place removed emphasis on the values of forest for amenity and environmental services at both local and global levels. Thus several countries with little need harvest timber from natural forests and strive to maintain extensive areas of forest in a near-natural condition.

According to Fearnside (1995) human impacts on Brazil's Amazon Forests are great and can be expected to respond to changes stemming from population growth and migration, economic activity and development policies. Some of human impacts on forest will be affected by climatic changes in other parts of Brazil and in other parts of the world.

Tropical moist rain forests are one of the world most important natural resources, principally because they contain the largest number of species of any known ecosystem. The world is losing 21 million hectares of tropical moist rainforest annually (Thampson and Duggie , 1996). According to Johnson and Sarre (1995) some 15.4 millions hectares of tropical forests are being cleared each year is prima facie evidence that at the moment such conditions do not generally apply. Hartshorn (1995) reported that unless sustainable development becomes much more prevalent in tropical forest would not survive far into the 21st century. Sustainable tropical forest must integrate forest conservation and economic development.

FAO (1991) stated that natural ecosystem in the tropics with their multiplicity of species, are too complex to be managed for sustainable yield purposes. The fact is that but for some outstanding exceptions the management, even of relatively simple monocultures of pine and eucalyptus, is either not applied or is weak in many developing countries. According to FAO, 1989 the Asian experience shows that sustainable timber production through natural regeneration of species is an option that should be given serious consideration. The Asian experience and the knowledge underlying it represent an informational base accumulated over a century, concerning sustained yield management, and converting a wide range of non-technical considerations. It is a source of information on which foresters everywhere should be able to draw on, for the development and improvement of forests.

Sudan is the largest country in Africa with an area of over 2.5 million square kilometer (about 1.0 million square miles). It has variable vegetation zones (types) ranging from desert and semi-desert in the north to high rainfall woodland Savannah in the south. Localized types as montane vegetation swamps and seasonal flood basin also occur. The soils range from pure moving sand and fixed sand in the north and northwest, cracking and alluvial soils in the center to skeleton soils and volcanic trash. Latric soils occur in parts of the southern region (Musa, 1992). According to FNC (1991) forests in the Sudan are estimated to cover about 23% of the total area of the country, ranging from Savannah woodlands in the north to gallery forests in the mountains and the southern part of the country. Due to the lack of forest inventories in the Sudan, data on forest resources in most cases is only rough estimates. The reserved forests make up only 1.4% of the total area of forests and woodlands.

At present over 19.0 million feddans (approximately 7.4 million hectares) of natural forests have been reserved. Sustainable management of natural reserves and natural forests outside the reserves in the Sudan should be conceived as a strategic approach to fulfil the national objectives including forest products besides combating desert encroachment, improving the productivity and reserving the declining trends of the natural systems (El siddig *et. al*, 1999).

According to UNEP (1999) an area of about 44 million hectares in the moist sub-humid, dry sub-humid and southern fringes of the semi-arid zones, is covered by natural forests and wood lands. Annual deforestation, which mostly takes place in all these zones, is 482.000 hectares (rate of 1.1 percent of the forest cover) 90 percent of which is for fuel and charcoal making. Musa (1992) stated that not far in the past the natural forests stretched almost unbroken over the vast plains of eastern and western Sudan. They also covered tops of hills and mountains and grew among the banks of rivers and water courses due to a number of factors including lack of management, uncontrolled grazing, shifting agriculture, and setting fires, the natural forests gradually diminished.

The objectives of this study are:

1- To study the relationships between the growth parameters of *Acacia seyal* in Wad Elkhesheid forest reserve, including diameter, height, form factor, basal area, volume per unit area and the stocking density.

2- To design a model for managing Wadelkisheid forest on sustainable basis.

CHAPTER TWO
LITERATURE REVIEW

2.1. Natural forest management in the world

To be successful, a forest management system has to be able to maintain a forest structure and distribution which can apply whatever combination of those requirements that circumstances impose, explicitly or implicitly on the forest (Osmaston, 1968). Baur (1989) stated that the reason for felling trees may change, and even the choice of trees to be felled but the technical problems remain the same. According to FAO (1989) the forest management intervention between forests and their immediate environments must be executed in and on the forest. Forest management thus covers what is done to a forest and how it is done, to meet certain specified purposes. But Osmaston (1968) and FAO (1989) added that for working purposes they can be grouped into broad classes of services and products, which warrant the continued occupation of land by forest. Those groups are infrastructure comprising the environmental protection amelioration influence of forests.

In principle, that is not different from the management of any other type of forest. As far as the regulatory aspects are concerned, there are only three options whether to harvest all the increment; less than the increment; or more than it is. In the silvicultural aspect, if it has been decided to harvest any increment at all then there are more but still not many options (FAO, 1989 and Davis, 1975). Monserud and Sterba (1996) reported that individual tree-based stand growth modeling could make accurate stand growth prediction for the full range of conditions between pure even-aged and mixed species uneven-aged stands. The control model in such a simulator is basal area increment for individual trees. According to UNSO (1991) several basic forestry issues raise a number of questions within the country whether the use of the remaining natural forest could be improved with good management, the problem of valuable and pasture land being lost to plantations which give a poor return to the rural people who formerly used the land; the possible disadvantages of plantation monoculture, and the debate over the value of fast-growing exotic species, particularly eucalyptus which has a reputation for being demanding on soil and ground water resources. Van Clay and Byron (1997) anticipated a significant shift in timber production from natural forest to plantations. This will be driven by several factors, including the reliability of supply uniformity of raw material and competitive pricing. Technically, there is no reason why plantations can not supply most of the world’s wood requirement by early next century. Even if demand exceeds the most optimistic projection, requirement may increasingly be satisfied from plantations, which over both economic and environmental advantages over natural forest production. Demand for the few specialty products that can be obtained only from natural forests may not increase greatly and can probably be satisfied from ecologically sensitive logging operations in areas where forests are retained primarily for their environmental and amenity functions.

Several recent definitions of sustainable forest management (SFM) have been proposed. World Commission on Environment and Development has defined SFM as a set of objectives, activities and outcomes consistent with maintaining or improving the forest's ecological integrity and contributing to people's well-being both now and in the future. A forest Management Unit (FMU) is defined as a clearly demarcated area of land covered predominantly by forests managed to a set of explicit objectives and according to a long-term management plan. Ecosystem integrity is defined as: the ability to support and maintain a balanced, integrated, adaptive biological community having a species composition, diversity, and functional organization comparable to that of natural habitat in the region (Ravi, *et. al.* 1996). Norton, *et al.* (1995) stated that the forest conservation reserve system is not currently representative of the full range of biodiversity. Many impacts related to forestry are significantly determined since they can:

1- Destroy and modify complex forest landscape and ecosystems.
2- Destroy and modify the natural and environmental heterogeneity of forest ecosystem;
3- Destroy, prevent or hinder ecological processes that are the basis for species persistence evaluation;
4- Destroy or significantly modify the habitat of species; and
5- Destroy individual organism and significantly modify population and assemblages of species.

Leewen, *et. al*. (1995) stated that although the farmers normally cut down the forest in order to establish crop land or pasture, their opinions are changing so that they are more aware of the future importance of trees and forest in their farming system, and could therefore, become an important group of wood producers. Farmers are now paying more attention to possible tree products resulting from the application of tree and forest management; these include wood and fruits, shade, water-conservation, and aesthetic and floristic value.

Payandeh, *et.al.* (1996) summarized the advantages of the basal area index employed as follows:

1. It serves as a valid measure of utilized site productivity, which is better, correlated with the main stand attributes than site index.

2. It produces variable stocking yield tables suitable for uneven-aged mixed species cover types.

3. Unlike the site index, they are applicable and inexpensive.

The basic improvement in mixed-wood yield estimation via basal area index should have broad application for other stand types particularly for the disturbed broad-leaved forests on southern Ontario and these in Eastern United States.

According to Osmaston (1968) in the entirely uneven-aged forest worked by the true selection system, trees of all ages and sizes are intermingled in every small unit of area such as 1 acre. The younger and smaller trees will occur in clusters partly under older and larger trees and partly in gaps or openings of the upper canopy. The oldest and largest trees will be scattered every-where in singles or perhaps couples. In such circumstances neither can the age of any tree be known nor the area of land occupied by any age-class. Felling, therefore, can not be distinguished by either area or age; nor can thinning be separated from final felling and yields so that definite areas can not be a part each year for either final or intermediate yields.

The normality of uneven-aged, selection forest that judged by the numbers of trees in each size-class, it must have a normal series of size-gradations, instead of the normal series of age gradations of the normal even-aged forest. Although it is obvious that a normal uneven-aged forest must contain more small trees than big ones per acre, it is difficult to devise a simple model, such as the triangle of normality for even-aged forest, to represent either the number or volumes of trees in the several size classes.

Norton, *et. al.* (1995) reported that it is argued that many forestry impacts on biodiversity may be irreversible or effectively irreversible, and the harvesting of many old growth eucalyptus forest ecosystems in New South Wales dose not appear to be ecologically sustainable. Essential components of a move towards sustainability include:

1- The establishment of a comprehensive conservation reserve network centered on old growth forest ecosystem on productive sites;

2- Enhanced off-reserve codes of forest practice in both public and private lands;

3- An ecologically conservative approach to forest management and;

4- The developments of a systematic ecological monitoring programme across the forest estate.

2.2 Natural forest management in tropical countries

In a silvicultural phase, the natural management of tropical forests still aims at taming the necessarily destructive harvesting of some trees into mechanism for replacing them (Schmidt, *et. al*. 1996).

According to Njorge (1992) the major problems facing forest management are:

1- Lack of public awareness and political will.

2- Technical constraints related to research, demonstration, extension and training.

3- Inadequate institutional framework and ineffective procedures for ensuring the integration of forestry in land husbandry and proper landuse.

4- Limited investment and lack of economic incentives.

Development assistance needs are:

1- Global inter-regional level

2- Regional /sub-regional level.

3- National level.

4- Summary of technical assistance requirements.

5- National programmes.

6- Potential for investment.

7- World food programme assistance.

Freezailah (1998) recognized that tropical timbers from natural forests are increasingly facing competition with timber from temperate forests against which tropical timber from sustainably managed natural forest is at a distinct disadvantage. It is quite clear that any further increase in management costs for tropical timber due to rigid standards for the sustainable management of natural tropical forest, timber certification, and other costs will render it increasingly uncompetitive of commodity timbers becoming available especially from plantation grown timbers from temperate countries. The future of tropical timber based on the sustainable management of natural tropical forests, is regretfully, more than bleak. It is in forest plantation that tropical countries have certain comparative advantages. Gatheara (1992) realized that the natural forest in Kenya are under strong pressure from the population, whose demand for agricultural land and grazing, as well as for woodfuel, has increased greatly in recent years. Harvesting of the natural forest has practically been discouraged due to over-cutting and of adequate information on the production potential. This has mainly been attributed to lack of appropriate management plans. The government realizes that the natural forests provide the protection of watersheds, natural ecosystems and genetic resources and all effort to ensure full conservation are being engaged. However encroachment of natural forest by squatters and persistent needs for excision continue to threaten sustainable development and management of the natural forest.

According to FAO (1991) there are common interests in the industrialized and developing countries in ensuring:

- That more orderly methods, and ecologically sound reason, are found for the conversion of forestland to sustainable agriculture.
- That the representative areas of natural forest vegetation are retained in national parks and other protected areas.
- That in the allocation of land to national parks and other protected areas, and in establishing a national forest estate, due account will be taken of the need fore conservation of forest genetic resources, primarily in the interest of local people, and of watersheds, for maintaining their hydrological functions.
- That significant part of natural forest vegetation, whether in the dry or wet tropics, is retained as forest estate to be managed for the production of goods and services in perpetuity and in the interest of rural people. The key to satisfying these common interests is the acceptance by all, that the objective of management in perpetuity of natural forest ecosystem, whether in the dry or wet tropics, must be in harmony with national polices and the interest of rural people.

Njorge (1992) summarized the requirements of the conservation of natural forest ecosystems as follows:

A / Prevention of degradation of the forests, while furthering development and wise use of natural resources.

B / Promotion of the sustainability of forest ecosystems for timber, wood etc, safeguard genetic resources.

C / Encouragement and facilitation of the integrated management of natural forest resources, wildlife, non-wood crops with little disturbance to ecosystems.

D / Promotion of the conservation and management of samples of ecosystems as reservoirs of species diversity.

Haule (1992) stated that the management of natural forests in Tanzania has traditionally been geared towards exploitation and only little has been done to ensure regeneration and sustainability of production. Selective harvesting concentrating on a few commercial species only has open up large areas for encroachment through road construction. Mechanized logging has been necessary in the rain forests and inappropriate harvesting methods have directly contributed to environmental degradation. Wood-fuel is mainly collected in natural forests and woodlands. Because of increasing distance from sources, a lot of valuable working time and human energy are lost by women and children in wood-fuel collection. This problem could be relieved if wood can be made available from village and private lots and properly managed woodlands.

According to Osmaston (1968) the control by silvicultural or other felling rules is a very simple method and often used in extensively managed tropical forests, particularly on those which are more or less irregular and under an early phase of management, a felling cycle is fixed and the forest divided into an equivalent number of sections and one section is worked in turn each year. The quantities of trees felled each year are controlled only by felling rules, which use simple silvicultural principles. The regulation of yield by numbers of trees is usually used more extensively, for example in large, irregular tropical forests which are often composed of many species only some of which are marketable and then only those above some fairly large minimum size. IUFRO (1975) stated that round the earth, circling satellites guarded the use of the natural resources. An international board can stop acute attacks on the environment. The cutting of forests without reforestation is strictly forbidden.

Njorge (1992) summarized the main problems and possible solutions for forest management in tropics as follows:

1/ Need to select and establish protected areas as part of national and regional networks.

2/ Need to assemble the basic information for the conservation of germplasms.

3/ Need to integrate protected area planning into overall landuse and regional planning.

4/ Need to integrate the management of protected areas and the conservation of genetic resources into rural development and to involve rural countries.

5/ Lack of incentives for ecosystem and genetic resources conservation.

6/ Lack of financial support for conservation generally and tropical forest ecosystem conservation in particular.

7/ Lack of awareness of the need for ecosystem and genetic resources conservation.

8/ Lack of trained staff at all levels.

2.3 Natural forest management in Sudan

The management of the natural forests is mined for woodfuel production besides minimization of the pressure exerted from various users, including mechanized farming that has caused the largest absolute damage to the forested area of the Sudan. At present, vast areas are completely bare of vegetation cover, except for isolated scattered natural under-stocked forests outside the reserves. Rural people living around those forests are exerting unbearable pressure on these forests in spite of guarding and patrolling them (El siddig *et. al*., 1999). The increasing demand for domestic fuel and timber necessitates the importance of rehabilitation of existing forests and expansion in forest plantation. This will help in preventing further degradation of natural tree cover in the country. The magnitude of deforestation in the country has been intensified for long time. Part of this destruction might be natural, but for a large extent it is a manmade disaster, as resulted from lack of integrated approaches in agricultural schemes together with other factors such as customary constraint (e.g. land tenure systems, favoring of growth in herd size etc,) (Atampugre *et. al*., 1991).

Ahmed (1989) stated that the southern part of the country has about 27% of the total population, while the northern part has about 43% of the forest resources but 73% of the country's population. Due to the high concentration of the population in the north and their practices, the forest resources have been exploited without securing regeneration and hence they suffer from an annual off-tack which is far beyond the sustainable yields, where the southern part enjoys a surplus in forest resources. The distribution of both population and forest resources are not compatible with the rational use of resource and severe depletion of forest resources has taken place in the most densely populated areas in the north. Depletion of forest resources has also taken place as a result of charcoal making for populated centers. According to World Bank (1986) deforestation can be attributed, partly to the clearing of land for cultivation and partly to the felling of trees for fuel-wood. It strengthens other processes of dry land degradation. Soil becomes less protected against the impact of wind, sun and rainfall when tree cover is reduced.

In the Sudan the deforestation is not caused only by energy needs, but by agricultural practices a well. Large areas have been cleared from trees due to horizontal expansion of agricultural holdings to counter-balance the decline in the productivity per unit area. This is especially so when the farming system is tied to cash economy (Mohammed and Elsheikh, 1983). Since the time when the reservation of the natural forests started, not a single reserved forest has been put under proper management, with the exception of the forest reserves along the banks of the Blue Nile River and its tributaries. All the management activities executed within the natural forest reserves are continued in the forest legislation and are mainly concerned with protection and patrolling exercised by the forest guards (El siddig *et. al.* 1999).

In natural ecosystems the nutrients released by plant litter are rapidly used by living plant tissues and become locked up in the biomass for the most of the forest's life. When a forest canopy is cleared and burnt, the nutrients are released, but the soil fertility is short-lived. Loss of vegetation cover, therefore, accelerates soil loss. Furthermore, the removal of soil cover from water catchment increases flood risk. The present trend of over-exploitation and mismanagement of forest resources can be reserved if the remaining forestlands are protected and the forest cover replaced where possible.

Although afforestation programmes have been attempted in several countries, the introduction of exotic species has not restored the ecological stability that existed when there was natural forest cover. The Sudan derives more than 75 percent of its energy requirement from fuel-wood estimated at 22 million m^3 per year. This is equivalent to about 400 million Acacia trees being uprooted annually for rainfed cropping (UNEP, 1999).

The Sudan is the largest country in Africa with an area of approximately 2.5 million Km^2. The northern half of the country lies between latitudes 14^0-22^0 N, it is an arid zone, characterized by very low summer rainfall within the range of 0 – 300 mm annually. The southern half, however, is comprised of two major divisions of the Savannah. The part that lies between 10^0 – 14^0 N is the low rainfall woodland Savannah. The other part that lies between latitudes 4^0 – 10^0 N is the high rainfall woodland Savannah. The Savannah region comprises about 45% of the total area of the Sudan, and is also the most densely populated region (Elsiddig and Hetherington, 1984).

FAO (1997) stated that, forest cover in Sudan is estimated to be 12% of the total area of the country, while it was 18% during early 1980s, and 36% during 1950s.

The Sudan, like many other countries, dose not have a reliable measure of its forest resources. The natural forest area was estimated at the time of inception of the Forest Department in 1901 as covering 40% of the total land area (Abdalla and Holding, 1988). Abdelsalam, (1998) stated that the cover of the semi-arid and Savannah woodland varies between those trees branching below breast height and others branching above.

Accordingly attempts for developing volume function is necessary to consider all problems derivation facing volume estimation, and aim toward derivation of functions for trees branching below or above breast height. Most of the trees distributed between latitude10^0 and 16^0 N are used for fuel, poles and sawn timber.

The concern of the protection of the natural forest resources in the Sudan started as early as 1908, when the first legislative measure was introduced for the creation of the forest reserves with the aim of conserving the natural forests and the supply of forest products for public purposes (Hummer, 1982).

According to Eldool (1995) the first attempt to manage natural forests in the Sudan was made in 1968, when six natural forests in the Blue Nile Province were incorporated in a management plan. El siddig and Hetherington (1984) stated that the main feature of Sudan forest policy and forestry development prior to World War II was the exploitation of the natural forest reserves rather than afforestation, except for Sunt plantations established along the Blue Nile.

There are various problems facing tree parameter measurements and volume estimation in natural structure in the Sudan. These forest resources which are distributed throughout the Sudan show different biological behavior reflected in their forms and shapes. From mensuration point of view these can be summarized in the following categories:

1. Trees that branch from ground level into multi-stems, such as *Acacia mellifera* (Kitir), and others.
2. Trees which are branching below dbh (1.3m above ground level) and above dbh, such as *Acacia seyal* (Talih)
3. Trees that mostly branch above dbh, such as *Sclerocarya birrea* (Humeid), (Abdelsalam, 1998).

CHAPTER THREE

STUDY AREA

3.1. Location and area

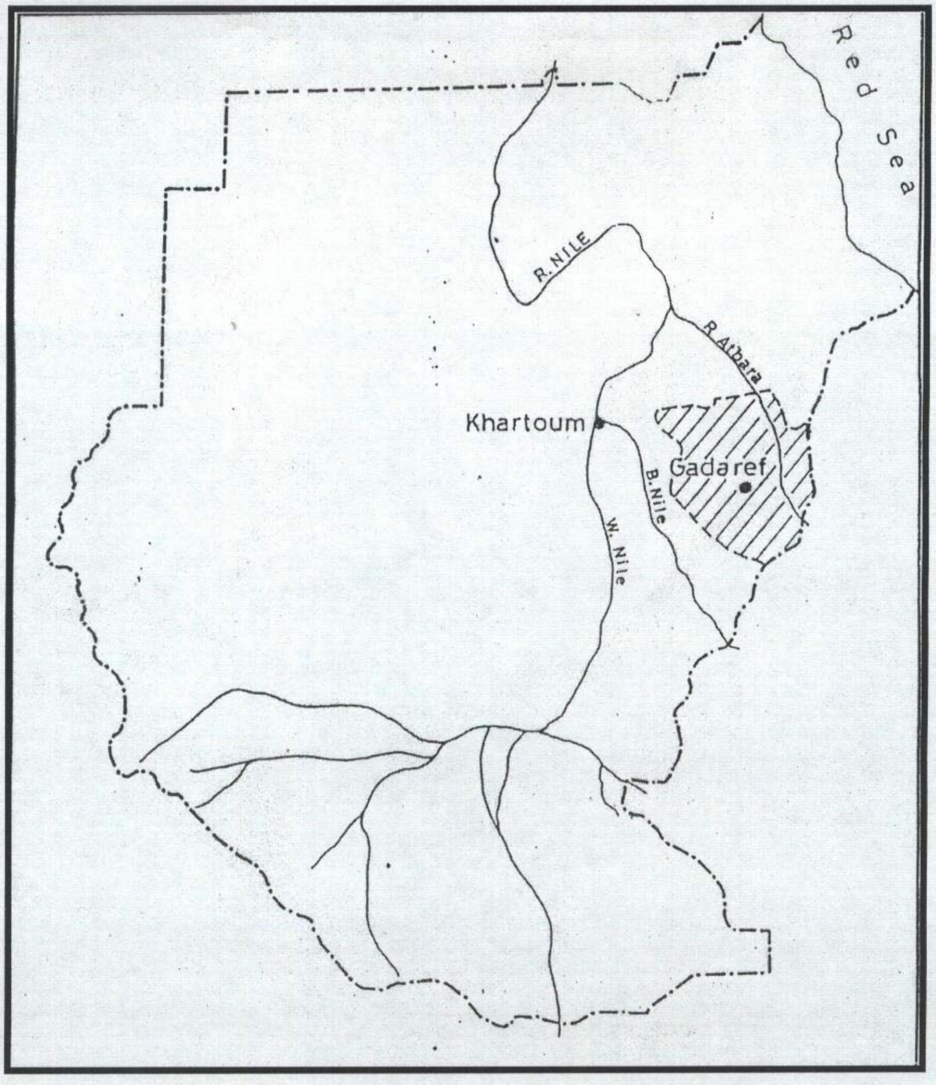
The Gadaref State lies between latitudes 13^0N and 16^0N, and longitudes 34^0E and 37^0E. it has an area of 78228 Km^2. The southern part of the state is situated in the eastern part of the poor Savannah belt while the northern portion lies within the semi-desert belt (Galal El Din, 1984).

Wad Elkhesheid natural forest reserve, where this study was carried out lies in Elrahad Province in Gadaref State (figure 1).

Wad Elkhesheid forest covers an area of approximately 2789 feddans (1171 hectares), and it was gazetted in 1972 with gazette number 1129.

Wad Elkhesheid natural forest reserve lies in the semi-arid zone in the part of south central clay plains near the transition between *Acacia mellifera* and *Acacia seyal-Balanites* Savannah Woodland.

Fig (1) Gadaref State Location



Source Soil Survey Administration, Wad Madani, 1976

3.2. Climate

3.2.1. Temperature

According to the Sudan Meteorological Authority 2000, the temperature in the Gadaref State ranges from 17.57^0C in January to the low 40s during the month of April and May (table 3.1).

Table (3.1) Temperature data for the Gadaref State (1990 – 1999).

Year	**Mean Temperature (^{0}C)**
1990	27.7
1991	28.7
1992	28.9
1993	28.9
1994	29.2
1995	28.8
1996	29.2
1997	29.2
1998	29.5
1999	28.5

Source: Sudan Meteorological Authority (2000)

3.2.2. Rainfall

The Gadaref State lies in the southern Butana Clay Plain. The Gadaref State gets between 600 and 800 mm of rain annually. This amount is crucial because most of the mechanized agricultural schemes are dry land farms. The mean annual rainfall of the Gadaref State between 1990 and 1999 was about 600 mm (table 3.2).

The state has a dry season for about eight months of the year. Most of the rain falls between June and October. Planting, weeding and harvesting are all centered on these four to five months. The nomadic pastoralists also migrate seasonally according to the rains.

Table (3.2) annual total rainfall in Gadaref State (1990 – 1999).

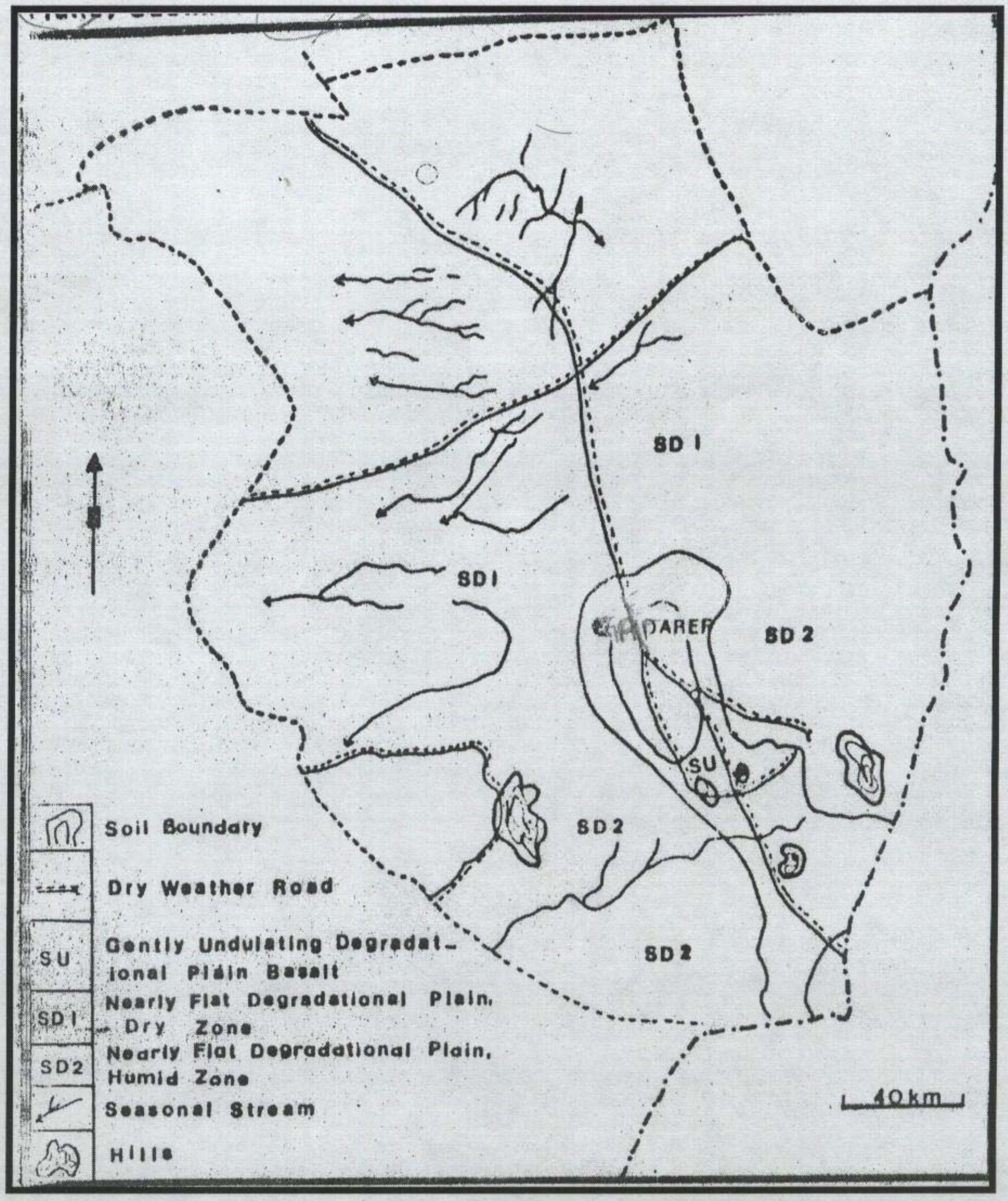
Year	Rainfall mm
1990	471.9
1991	418.8
1992	577.1
1993	777.3
1994	638.4
1995	530.0
1996	552.0
1997	589.8
1998	601.3
1999	863.6

Source: Sudan Meteorological Authority (2000)

3.3. Geology

The Gadaref State lies within the south Central Clay Plain area. The elevation of the undulating plains is from 550 meters to 650 meters above sea level. Flatter plains slope away from the Gadaref – Gallabat Ridge down to 450 meters. The predominant formation in the southern part is a large area of tertiary basalt surrounded by Mesozoic sandstone or mudstones of the Gadaref formation. The rocks of these formations are covered by thick layers of Quaternary elastic material which is mainly heavy clay in the Gadaref region (Van Der Kevic, Burymah and Ibrahim, 1976), (figure 2).

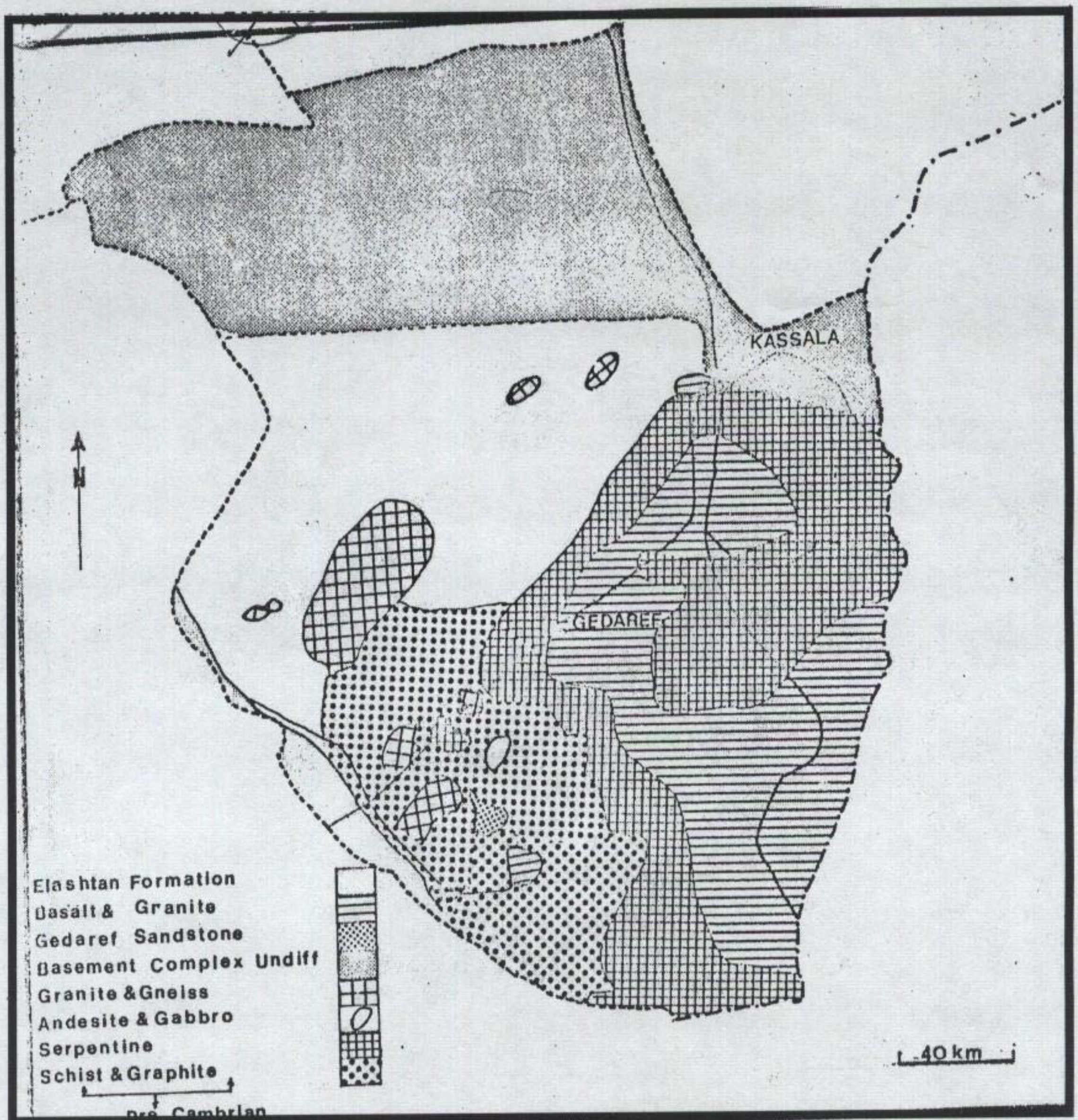
Fig (3) Gadaref State Soil



3.4. Soil

Mackinnon (1948) describes the soils of the Gadaref Region as chocolate clays. He says that the clay content of the soils increases as one heads south and east through Kassala Province. The average ground slope is 2.5 meters per kilometer. There are limited areas of " chocolate" cracking clays formed in situ from basalt. These areas are found mainly around Gadaref. Areas of clay were found to contain quartz stone on the surface. They are widely spread and are good for cultivation. Rain-land clay plains crack deeply in winter and crumble during the dry season. During the wet season they are spongy. As a result of their high permeability, little water is lost to run-off, (figure3).

Fig (2) Geology of Gadaref State



SOURCE: SOIL SURVEY, WAD MEDANI, 1976

3.5. Soil degradation

Ahmed (1989) discusses the effect of soil degradation around water points. He states that overgrazing around water points results in a gradual inability of pasture soils to support rich plant cover because the percentage of organic matter in the soil decreases and the soil becomes dry. Paucity of groundcover results in increased run-off and wind erosion. He took samples from soils around water points and found that there was a decrease in silt and clay percentage in the soil, an increase in the percentage of soluble salts because of a continuos addition of urine from large herds around the water points and a decrease of pH levels as a result of accumulation of acids from urine, and increase in organic matter because of incorporation of animal manure into the soil.

3.6 Water courses

Galal El Din (1984) stated that many watercourses traverse the Gadaref State; the two major hydrological factors are the Rahad River and the Atbra River, on the southwestern and northeastern boundaries of the State respectively. The major Khors of the State are Khor Farga and Khor Magadam, which traverse Gadaref Town.

3.7 Vegetation

Harrison and Jackson (1958) in their paper on the vegetation of major ecological divisions in the Sudan place the Gadaref State into two sub-divisions of woodland Savannah. They define woodland Savannah as "any mixed type of vegetation composed of grass with bushes and/or trees is determined by the frequency and intensity of fires". The trees of low rainfall woodland Savannah in the drier parts are nearly all thorn trees of low stature. They are principally Acacia species with some thorn bushes and shrubs, including thickets of *Acacia mellifera*.

The Gadaref region is divided into two sub-divisions of low rainfall woodland Savannah:

A/ *Acacia mellifera* thorn land:

The dominant tree species of this area is *Acacia mellifera,* associated with *Cadaba glandulosa, Cadaba rotundifolia* and *Boscia senegalensis*. The rainfall ranges between 100 and 570 mm.

B/ *Acacia seyal – Balanites* Savannah:

Acacia mellifera thorn land passes gradually into *Acacia seyal – Balanites Savannah* at about the 570 mm isohyte. *Acacia seyal* is distributed throughout usually more or less mixed with *Balanites agyptiaca*. The rainfall ranges between 570 and 800 mm.

3.8 Landuse

There are four major types of landuse in the Gadaref State. Irrigated agriculture is found in the northeast at Halfa Elgadida, and in the southeast at the Rahad Scheme. The northern half of the State is predominantly pastoral, while mechanized rain-fed agriculture dominates the southern half of the State. Traditional (Harig and Bilad) agriculture is scattered throughout the State (Galal El Din, 1984).

Mackinnon (1948) described the Gadaref area as vast land occupied by Acacia tall grass forests as well as open grass plains. For the present situation of Gadaref State it can be generally said that very little of natural forests remain and most of the area is occupied by traditional and mechanized farming.

Eldool (1995) stated that, the widespread expansion of agriculture has severely reduced traditional livestock pastures and passages which results in conflicts between nomads and settled farmers and consequently results in great pressure to the remaining forests (table 3.3).

Table 3.3 landuse change 1941 – 1991

Landuse	Area in 1941			Area in 1991		
	Km2	Million Fed.	%	Km2	Million Fed.	%
Farm lands	3.150	0.75	8.75	26.000	6.2	72.1
Forest/ woodland	28.250	6.75	78.5	6.700	1.55	18.0
Kerrib	1.300	0.30	3,6	1.300	0.30	3.6
Ljebes, Khors ,Rivers	3.300	0.80	9,51	2.000	0.55	6.3
Total	36.000	8.6	100	36.000	8.6	100

(Source: Eldool, 1995).

3.9 Deforestation

According to Musnad (1982) charcoal production and agricultural expansion are the major causes of widespread deforestation in Gadaref State. First, overgrazing and use of wood for industry are also contributing factors. With the introduction of tractors, crawler tractors and machines, large areas of land have been easily cleared of trees and bushes. Although the Mechanized Farming Corporation recommended that farmers establish tree shelterbelts on their land, this recommendation is generally not followed.

Acacia seyal had been found in pure, thick stands in Gadaref State. The trees are all about the same age and size, making them easy to cut. When burned *Acacia seyal* produces excellent charcoal. These characteristics make charcoal production from *Acacia seyal* very profitable. In fact, illicit charcoal producers have gone deep into forests away from main roads to cut their trees.

3.10. Population

3.10.1 Distribution and migration

Only 107 out of 1000 persons in the Gadaref State are foreign born and most of them are found in the age group 10 – 40 years. Obviously these are children of Sudanese who had lived abroad earlier or migrants from abroad. Urban population is 24.0% of the population. 60.9% of the population is born in the same state and only 31% of them are lifetime migrants. Lifetime migrants constitute 31.4 % of urban population and 30.9 % of rural population (Central Bureau of Statistics, 1993).

3.10.2 Educational characteristics

According to the Central Bureau of Statistics 1993, the literacy rate for person's 6 years and over is 59.1 percent for both sexes (69.6 percent for males and 48.1 for females). In urban areas the literacy rate is 57 percent for both sexes (72.3 percent for males and 55.7 for females). In rural areas the literacy rate is also 57 percent for both sexes (68.4 percent for males and 45.2 for females).

3.10.3 Housing conditions

73.5% of the households in Gadaref State live in huts (Gothias), 22.3% in manzils with one floor; and 3.7% live in assorted categories of housing. The percentage of population who live in there own dewellings is 72.6 percent in urban and 93.1 percent in rural areas. In both arban and rural areas, the major sources of fuel is wood, the percentage of population depending upon wood as fuel is 61%. 76.4% of the population depends upon Kerosene for lighting, 31% of urban population has electricity against only 8.4% in rural areas. Only 28% of the population of Gadaref State have the benefit of piped water and 32% depend upon wells and donkeys for their water supply (Central Bureau of Statistics, 1993).

CHAPTER FOUR

MATERIALS AND METHODS

4.1 Data collection

The methods of data collection followed in this study are tree measurement (Mensurational work). The data collection was carried out based on:

- operational inventory
- mensurational work

4.1.1 Operational inventory

The total area of Wad Elkhesheid forest is 2789 feddans (1171ha). Systematic circular sample plot was used in this method. The area of each sample plot was 0.1ha (radius = 17.85m) and sampling percentage is 5%.

4.1.2 Mensurational work

The mensuration work involved**:**

- tree identification
- measuring tree parameters; measurement including diameter at breast height (in cm), tree height (in meter) and form factor determination.

4.1.2.1 Tree identification

At first the base line was determined, and the bearing towards inside the forest was read. 40 meters were measured in the direction of the bearing in order to avoid marginal trees. The end of the 40 meters represented the center of the circular sample plot (r = 17.85 cm). After the demarcation of the boundary of the sample plot, and then of diameter at breast height (dbh) of all trees and heights of three trees representing the highest, the medium and the lowest diameters are measured in cm.

For the trees at the border of the sample plot the distance from the center of the sample plot to the tree was measured accurately. If more than half of the tree was inside the sample plot , it was counted, if more than half was outside, it was neglected, if it was exactly at the border (half in half out), it was measured in one case and neglected in the next case.

4.1.2.2 Diameter at breast height (dbh)

Inside each sample plot the diameter at breast height was measured for every tree, using a 1.3 m long stick to determine the exact measurement point. At all measurements care was taken to ensure that the caliper was maintained horizontally around the tree. The same procedures were repeated for all the trees inside each sample plot. All the diameter readings were recorded in a special sheet to the nearest millimeter.

4.1.2.3 Tree height

The measurement of the tree height was carried out with the aid of a 30 m tape and a hypsometer.

4.1.3 Form factor

One hundred and thirty five trees were felled down to determine the form factor.

4.13.1 Tree felling

After determining the tree to be felled, its diameter at breast height was marked and measured. The total height was also measured in meter. Then the tree was cut down.

4.1.3.2 Sectioning

Once the tree was on the ground it was devided into one meter sections. Then the mid-diameter in cm for each log was determined using a caliper.

4.2 Data analysis

4.2.1 General

In this study the method of data analysis concerned the managerial aspect involving computation and regression analysis spread sheet programme (Quatro – Pro), available at the Faculty of Forestry, was used in the data entry and has the power of arranging and tabulating the data in the way that can easily be checked and reviewed. Two sets of data were prepared in spread sheet, one for the main measurements in which survey line, sample plot, tree number, diameter at breast height, tree species and remarks were entered in separate columns.

The other spreadsheet for form factor measurements in which tree number, height in meter, diameter at breast height in cm and form factor were entered in separate columns.

This programme has the power to do all the simple statistical computations. For advanced analysis Statistical Analysis System (S.A.S) was used.

4.2.2 Regression analysis

Regression analysis is a widely used approach for fitting and evaluating mathematical models involving several variables (Freese, 1964).

In this study step-wise multiple linear regression is the main tool used in analyzing the data to calculate the volume of Talih trees and develop height/diameter relationship and form factor, height and diameter regression.

The general regression equation was as follows:

$Y = b_0 + b_1X_1 + b_2X_2 + \ldots\ldots\ldots b_r X_r$

Where:

b_0 = the regression constant

b_1 .... b_r = the regression coefficients

X_1 .... X_r = the independent variables

4.2.3 Coefficient of correlation

It is the ratio of the explained variation to the total variation (Spiegel, 1981). Since this ratio is always none-negative, it is denoted by $r^{2.}$ The quantity r^2 is called the coefficient of correlation and given by:

$$r = (+/-) \sqrt{\text{explained variation / total variation}}$$

$$r = (+/-) \sqrt{\sum (y - y^-)^2 / (x - y^-)^2}$$

r^2 = a quantity which varies between +/- (1).

The best regression model is the one giving a correlation coefficient close to one or brings the greatest coefficient of correlation among all (Milton and Arnold, 1986).

4.2.4 Volume calculation

The section method and Huber' s formula are commonly used in Sudan for practical and training purposes. Elsiddig (1980) used the equation for the construction of volume tables of *Acacia nilotica* in the Fong Region of the Sudan. Idris (1997) reported that Huber' s formula is simpler, more accurate, more economic than Smalian' s and gives results closer to that given by Newton's and by displacement method, particularly when logs are short (1 - 2 meters long). Hence Huber' s formula was used in this study.

Huber' s formula was used for tree volume and form factor calculation. The volume of each log or branch was calculated using the formula:

$V = \pi /4 \times d_m^2 \times L$

Where:

V = volume of log or branch (in meter^3)

d_m = mid – diameter of log or branch (in meter)

L = log or branch length (in meter)

The total volume of the tree (in cubic meter) was obtained by summation of logs volumes.

The volume of the cylinder corresponding to each individual tree having the same diameter at breast height and height. The volume of each cylinder was calculated using the formula:

$V = \pi /4 \times d^2 \times h$

Where:

V = cylinder volume (in cubic meter)

d = diameter at breast height (in meters)

h = tree height (in meters)

By dividing the volume of each individual tree by the cylinder's volume we get the form factor of each of the sample trees.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 General

The use of computers and regression techniques provides objective means of developing tree parameters relationships and uses the equations for prediction of required parameters.

In the present study the developed equations concerning height/diameter, form factor/diameter, form factor/height and volume relationship to height and diameter are useful tools for the inventory of natural forests in Sudan.

5.2 Height – diameter relationship

The procedure which enables us to decide whether to accept or reject a hypothesis or determine whether observed samples differ significantly from expected results, are called test of significance, test of hypothesis or rules of decision (Spiegel, 1981).

In this study the relationship between height (dependent variable) and diameter at breast height (independent variable) was examined for Talih. Table 5.1 shows this relationship.

Table 5.1 Regression analysis of height and diameter relationship for Talih trees in the study area.

Equation No	Equation	Probability	R2
5.1	**h** = 3.3526 + 0.2913dbh	0.0001	0.66
5.2	h = 3.5941+0.2602dbh+0.0007dbh^2	0.1383	0.66

Where:

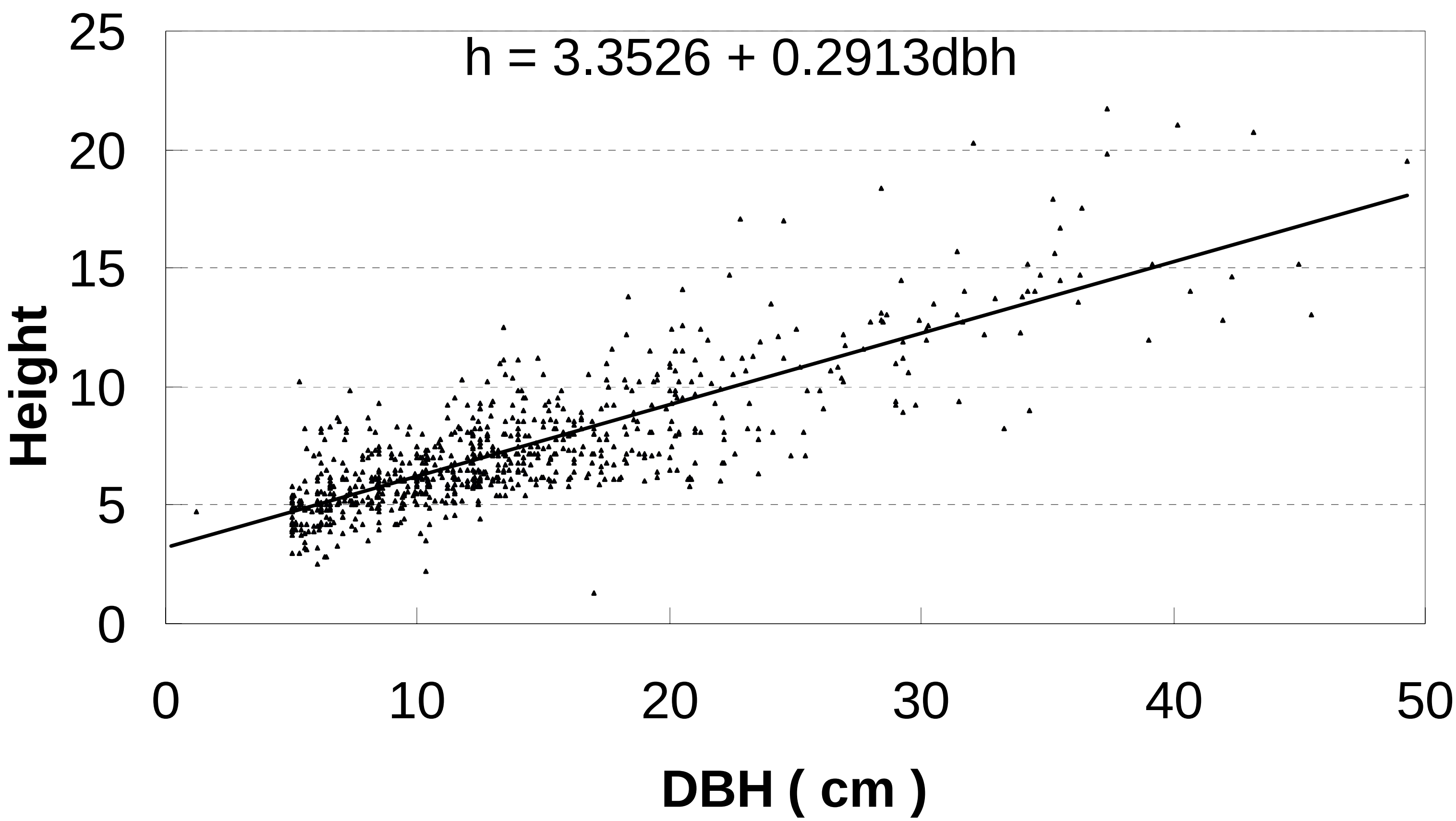
h = height (cm)

dbh = diameter at breast height

When the relationship between height (dependent variable) and diameter at breast height (independent variable) of Talih trees was studied, two equations were constructed (table 5.1).

Although the coefficient of determination r^2 for equation 5.1 and equation 5.2 was rather low (0.66), but equation (5.1) was used because the model was composed of statistically significant variable ($P<0.0001$) compared to that for equation (5.2) as it was ($P<0.1383$) (Fig 4).

Fig (4) Relationship between height and diameter at breast height (dbh) for Talih trees in the study area



When the study was carried out by using linear regression method of the response and prediction variables for Talih trees the linear regression models were fitted and expressed as:

$Y = a + bx$ (a straight line, simple linear regression).

Y **=** the response or dependant variable (in this study it refers to the height).

a = the regression constant.

b = the regression coefficient**.**

x = the independent or predictor variable (in this study it refers to the diameter at breast height).

5.3 Form factor

The form factor is the reduction factor by which the product of basal area and tree height (cylinder) has to be multiplied to obtain the tree volume. The form factor is important for determining standing volumes. It is theoretical factor, which can not be determined without extensive measurements on felled trees.

The form factor of the Talih trees growing in the study area showed a great variation ranging between 0.22 to 0.68. Therefore, the form factor was used as a parameter for establishing relationship with height, diameter multiplied by height, diameter square multiplied by height and diameter square. To find this relationship, the form factor was used as a dependant variable; whereas the other variables were used as predictor variables. Table 5.2 shows this relationship.

Table 5.2 Regression analysis for selection of best-fitted form factor equation for Talih trees in the study area

Dependant Variable	Independent variable	Equation	Prop>F	r^2
FF	dbh	$0.5695 – 0.0089dbh$	0.0001	0.62
FF	h	$0.7292 – 0.0349h$	0.0001	0.60
FF	$dbh \times h$	$0.5244 - 0.0006dbh \times h$	0.0001	0.61
FF	dbh^2	$0.5042 – 0.0002dbh^2$	0.0001	0.61
FF	$dbh^2 \times h$	$0.4918 – 0.0001dbh^2 \times h$	0.0001	0.56

Where:

FF = form factor

h = height (m)

dbh = diameter at breast height (m)

Forward selection procedure for dependant variable (form factor) was followed in the analysis of this study in order to select the equation of the best fit. Different tests were carried out to facilitate the selection of equations of the best fit. The first test was the determination of the increase of r^2 by addition of independent variables into the model. Another test was the (Prop>F) which will supplement the first test for the fitness.

The independent variables used to select the best equation of the form factor are diameter, height, diameter multiplied by height and diameter square. Table 5.3 shows the selection procedure.

Table 5.3 Stepwise procedure for selection of equation for best-fitted form factor for Talih trees in the study area.

Equation No	Equation	R^2
5.3	$FF=0.5695-0.0089dbh$	0.62
5.4	$FF=0.6403-0.0056dbh+0.0154h$	0.63
5.5	$FF=0.6849-0.0084dbh-0.0196h+0.0003dbh \times h$	0.64
5.6	$FF=0.7709-0.0041dbh-0.0449h+0.0017dbh \times h\ 0.0005dbh^2$	0.66

Where:

h = height (m)

dbh = diameter at breast height (cm)

FF = form factor

During the fitting process for selection of best fitted form factor equation, the regressors dbh, h, dbh multiplied by h and dbh^2 were selected by the programme as the most significant independent variables that removed the highest variability within the form factor (dependant variable).

In this study the value of the coefficient of determination (R^2) was 0.62, 0.63 when h was added, and it increased to 0.64 when dbh multiplied by h was added and 0.66 when dbh^2 was added.

Although equation (5.5) and equation (5.6) have high R^2 (0.64 and 0.66 respectively) compared to equation (5.4), but equation (5.4) was used for calculation of the form factor for Talih because when height (h) was added to equation (5.4) the probability was 0.0212 (highly significant) where as it was 03099 for dbh multiplied by h when added to equation (5.5) and 0.2323 for dbh^2 when added to equation (5.6).

5.4 Basal area and volume

The results of the analysis of the basal area and volume per hectare for Talih are shown in table 5.4.

Table 5.4 The basal area and volume per feddan for Talih trees in the study area

Parameter	**Mean**	**SV**	**CV %**
DBH	11.60	7.59	68.58
H	7.44	2.61	35.11
F	0.48	0.20	42.57
B / FED	0.44	1.54	100.06
V / FED	3.36	13.52	168.95
NOTR / FED	44	103.35	98.76

Where:

DBH = diameter at breast height (cm)

H = height (m)

F = form factor

B/ FED = average basal area per feddan (m^2)

V/FED = average volume per feddan (m^3)

NOTR/FED = average number per feddan

SV = standard deviation

CV = coefficient of variation

The low coefficient of variation in height (35.11) indicates that the degree of homogeneity is relatively high. Therefore, the big variation in basal area and volume is attributed to the variation of tree diameters and this can be accepted as long as our forest is a natural one.

5.5 Yield regulation

5.5.1 General

The aim of the management planning is to develop and maintain a size–class structure for the most important species (*Acacia seyal*) which is utilized as fuel–wood (firewood and charcoal) besides other environmental benefits.

5.5.2 Mean annual increment (MAI).

It is difficult to talk about mean annual increment, since we are dealing with a natural forest with unknown age. To make a start we assume that the trees ready for felling (target trees) are 15 years old based on the practical of the Forest National Corporation (FNC).

To calculate the mean annual increment for Talih species, the average diameter at breast height per sample plot (d) was divided over rotation period (R).

M.A.I = d / R

The result of calculation of the M.A.I of diameter from data records is that the M.A.I of Talih trees in the study area is 0.77 cm / year.

5.5.3 Natural regeneration

Survey and assessment of the natural regeneration was conducted over the whole area of the forest. The results show that the forest is a poor with natural regeneration (average number of regeneration per feddan is 23).

The weakness of the natural regeneration refers to the over-grazing that occurs in the forest during the dry season in addition to the activities of charcoal production inside the forest.

5.5.4 Management system

The management of the forest will concentrate in development and maintenance of the diameter-classes profile from the stage of regeneration to maturity of Talih trees for satisfaction of the community needs with respect to fire-wood, building poles and non-timber products (gum food, fodder and local medicines) besides other environmental benefits and bio-diversity conservation.

The different kinds of activities are accordingly prescribed annually. Presently selection of the Talih trees will be implemented annually.

Other species will not be neglected but left to develop themselves naturally. Those are the least abundant species and least used. They will not be continuously under observation.

5.5.5 Selective felling

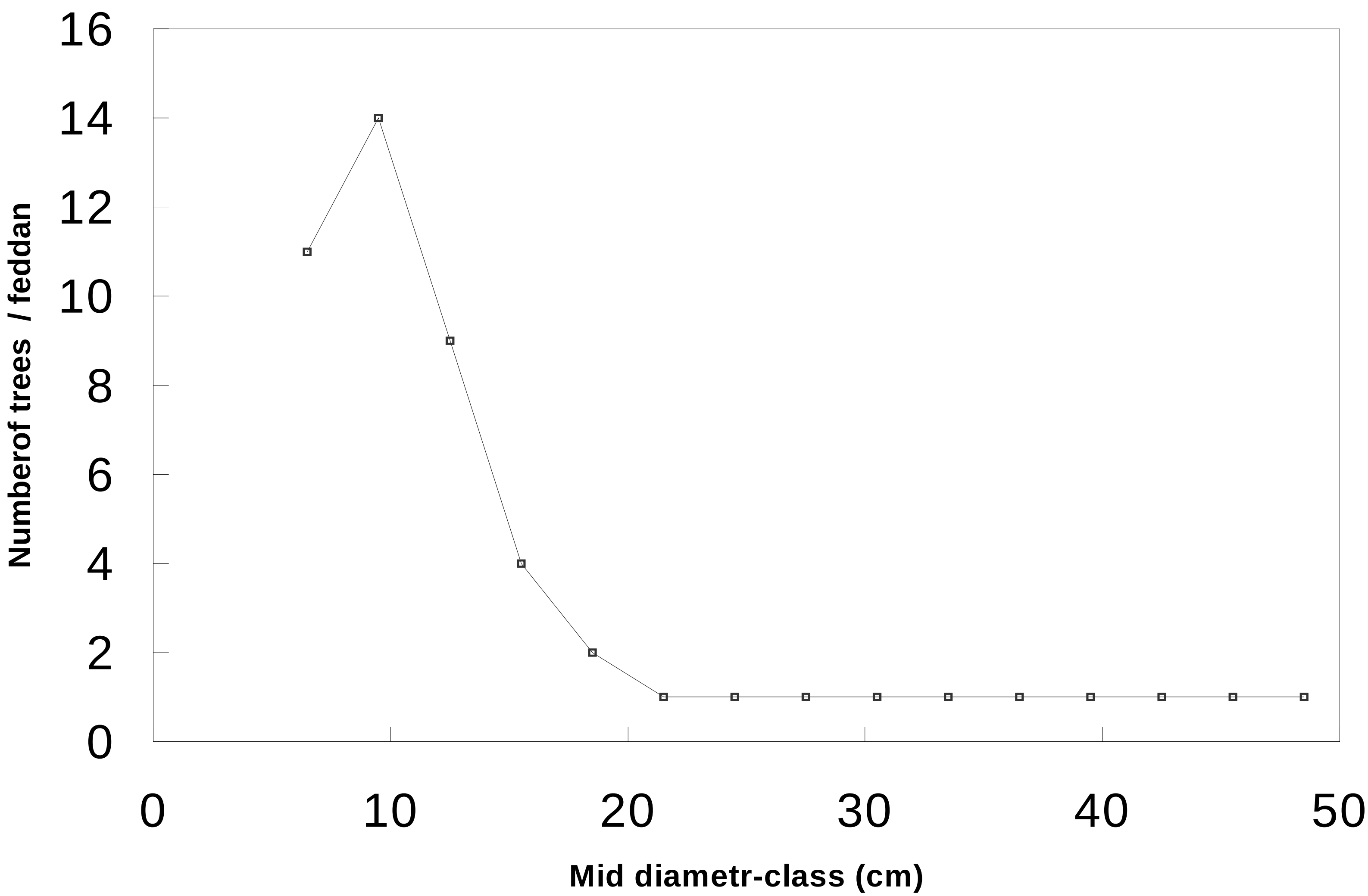
The management system to be adopted for Talih trees for wood production is the selective felling system. As the development of trees in the large size-classes is slow, selective felling system will be practiced annually (Table 5.5).

Table 5.5 The relationship between Talih mid-diameter class and number of tree per feddan.

Mid-diameter class	Number of tree per feddan
6.5	11
9.5	14
12.5	9
15.5	4
18.5	2
21.5	1
24.5	1
27.5	1
30.5	1
33.5	1
36.5	1
39.5	1
42.5	1
45.5	1
48.5	1

The individual tree diameter extends over a wide range between 5cm to 49.8cm. However the diameter distribution of Talih trees in the study area indicates that sustainable production of firewood from Talih trees is possible if the study area is put under management following selective felling system. Natural regeneration protection will result in diameter development to fill the gap between the smallest diameters shown in table 5,5 and facilitates sustainable development and prediction, (figure 5).

Fig (5) Relationship between mid diameter-class and number of trees per feddan for Talih trees in the study area



5.5.6 Compartmentaion

Wad Elkhesheid forest has been divided into ten compartments partly pondered by natural, partly by artificial features.

From data records, the analyses involved calculations on:

- Average number of trees per feddan
- Average volume per feddan (Table 5.7).

Table 5.6 The compartments in the study area with their area, volume, and number of trees per feddan.

Compartment No	Area / fed	Volume / tree	Volume / fed	No of tree / fed
1-	256	.013	5.6	42
2-	276	0.11	4.7	44
3-	256	0.06	2.5	45
4-	241	0.06	2.7	43
5-	276	0.08	3.7	45
6-	265	0.06	2.3	42
7-	307	0.08	3.7	46
8-	316	0.041	17.9	44
9-	332	0.09	4.1	44
10-	253	0.02	1.0	45

The calculated mean annual increment (M.A.I) of the volume in the study area is 11907 cubic meters. Following the principle of sustainability of growth and yield, the harvest should not exceed

M.A.I and the area of the annual coupe should produce approximately the M.A.I

However, the calculation procedure (sum of total standing volume divided by rotation period) did not take into account the standing volume of the small crop (less than 5centimeter diameter). Accordingly, the harvested volume in the form of target trees is concentrated within the largest sizes, which started with a removal equal to M.A.I in the year 2003 and gradually increases until it reaches 1907 m^3 from the target trees. This approach has been adopted in order to bridge the gap between the smallest size-classes and largest size-classes.

To calculate the volume to be cut annually the following equation was used:

$$Vol = Ba / tree \times H \times F \times NOTR / fed \times A / fed$$

Where:

Vol = volume to be cut annually (m^3)

Ba / tree = basal area per tree (m^2)

H = height (m)

F = form factor

NOTR / fed = number of trees per feddan

A / fed = area per feddan

To determine the height of Talih trees the following equation was used according to the results of regression analysis of height and diameter relationship for Talih trees.

$h = 3.3526 + 0.2913\ dbh$

Where:

h = height (m)

dbh = diameter at breast height (cm)

To determine the form factor of Talih trees the following equation was used according to the results of analysis for selection of the best fitted equation of form factor.

$F = 0.6403 - 0.0056dbh + 0.0154h$

Where:

F= form factor

dbh = diameter at breast height (cm)

h = height (m)

The harvesting schedule for the compartments in the study area is provided in table 5.7.

Table 5.7 shows the harvesting schedule in the study area, 2003 - 2022

Table 5.7.1 shows harvesting schedule in the study area for 2003

Year	**Compartment**	**Area (fed)**	**Operation**	**Number of stems per Diameter class**			**Volume to be cut**
				47 – 49.9	44- 46.9	41- 43.9	
2003	8	316	Selective felling	316			884.8
	9	332	Selective felling		332		664
	7	307	Selective felling			200	340
Total				316	332	200	1888.8

Table 5.7.2 shows harvesting schedule for 2004

Year	**Compartment**	**Area (fed)**	**Operation**	**Number of stems per Diameter class**				**Volume to be cut**
				41 - 43.9	38- 40.9	35- 37.9	32- 34.9	
2004	7	307	Selective felling	107				161.6
	8	316	Selective felling	316				477.2
	8	316	Selective felling		316			395
	5	276	Selective felling			276		278.8
	8	316	Selective felling			316		319.2
	8	316	Selective felling				316	252.8
Total				423	316	592	316	1884.6

Table 5.7.3 shows harvesting schedule for 2005

Year	**Compartment**	**Area (fed)**	**Operation**	**Number of stems per Diameter class**		**Volume to be cut**
				29 - 31.9	26 - 28.9	
2005	7	307	Selective felling	307		208.8
	8	316	Selective felling	1896		1289.3
	1	256			256	133.1
	2	276			276	143.5
	4	241			241	125.3
Total				2203	771	1900

Table 5.7.4 shows harvesting schedule for 2006

Year	**Compartment**	**Area (fed)**	**Operation**	**Number of stems per Diameter class**			**Volume to be cut**
				26 – 28.9	23 – 25.9	20 –22.9	
2006	8	316	Selective felling	2528			1390.4
	5	276	Selective felling		276		115.9
	8	316	Selective felling		316		132.7
	1	256	Selective felling			768	238.1
Total				2528	592	768	1877.1

Table 5.7.5 shows harvesting schedule for 2007

Year	Compartment	Area (fed)	Operation	Number of stems per Diameter class		Volume to be cut
				20 – 22.9	17 – 19.9	
2007	2	276	Selective felling	552		182.2
	5	276	Selective felling	552		182.2
	6	269	Selective felling	807		266.3
	8	316	Selective felling	948		312.8
	1	256	Selective felling		2048	491.5
	2	276	Selective felling		1656	397.4
Total				2859	3704	1832.4

Table 5.7.6 shows harvesting schedule for 2008

Year	Compartment	Area (fed)	Operation	Number of stems per Diameter class	Volume to be cut
				17 – 19.9	
2008	4	241	Selective felling	964	250.6
	5	276	Selective felling	1656	430.6
	6	269	Selective felling	1345	349.7
	7	307	Selective felling	1535	399.1
	8	316	Selective felling	1580	410.8
Total				7080	1840.8

Table 5.7.7 shows harvesting schedule for 2009

Year	**Compartment**	**Area (fed)**	**Operation**	**Number of stems per Diameter class**	**Volume to be cut**
				14 – 16.9	
2009	1	256	Selective felling	2304	460.8
	2	276	Selective felling	1932	386.4
	3	256	Selective felling	2560	512
	4	241	Selective felling	1446	289.2
	5	276	Selective felling	1208	241.6
Total				9450	1890

Table 5.7.8 shows harvesting schedule for 2010

Year	Compartment	Area (fed)	Operation	Number of stems per Diameter class	Volume to be cut
				14 –16.9	
2010	5	276	Selective felling	1276	280.7
	6	269	Selective felling	1345	295.9
	7	307	Selective felling	2149	472.9
	8	316	Selective felling	2528	556.2
	9	332	Selective felling	1422	312.8
Total				8720	1918.5

Table 5.7.9 shows harvesting schedule for 2011

Year	Compartment	Area (fed)	Operation	Number of stems per Diameter class		Volume to be cut
				14 – 16.9	11 – 13.9	
2011	9		Selective felling	1566		375.8
	1		Selective felling		2816	450.6
	2		Selective felling		2208	353.3
	3		Selective felling		2560	409.6
	4		Selective felling		1880	300.8
Total					9464	1890.1

Table 5.7.10 shows harvesting schedule for 2012

Year	Compartment	Area (fed)	Operation	Number of stems per Diameter class	Volume to be cut
				11 –13.9	
2012	4	241	Selective felling	289	52
	5	276	Selective felling	1932	347.7
	6	269	Selective felling	2959	532.6
	7	307	Selective felling	2456	442.1
	8	316	Selective felling	2528	455
Total				10164	1829.4

Table 5.7.11 harvesting schedule for 2013

Year	Compartment	Area (fed)	Operation	Number of stems per Diameter class		Volume to be cut
				11 – 13.9	8 – 10.9	
2013	9	332	Selective felling	3984		796.8
	10	253	Selective felling	2530		506
	1	256	Selective felling		2560	332.8
	2	276	Selective felling		1964	255.3
Total				6424	4524	1890.9

Table 5.7.12 shows harvesting schedule for 2014

Year	Compartment	Area (fed)	Operation	Number of stems per Diameter class	Volume to be cut
				8 – 10.9	
2014	2	276	Selective felling	1348	202.2
	3	256	Selective felling	1536	230.4
	4	241	Selective felling	1928	289.2
	5	276	Selective felling	2760	414
	6	269	Selective felling	2690	403.5
	7	307	Selective felling	2149	322.4
Total				12411	1861.7

Table 5.7.13 shows harvesting schedule for 2015

Year	Compartment	Area (fed)	Operation	Number of stems per Diameter class		Volume to be cut
				8 – 10.9	5 – 7.9	
2015	9	332	Selective felling	3652		584.3
	10	253	Selective felling	3289		526.2
	2	276	Selective felling		2208	220.8
	3	256	Selective felling		5120	512
Total				6941	7328	1843.3

Table 5.7.14 shows harvesting schedule for 20016

Year	Compartment	Area (fed)	Operation	Number of stems per Diameter class	Volume to be cut
				5 – 7.9	
2016	4	241	Selective felling	3615	433.8
	5	276	Selective felling	2484	298.1
	6	269	Selective felling	2152	258.2
	7	307	Selective felling	5219	626.3
	9	332	Selective felling	2280	273.6
Total				15750	1890

Table 5.7.15 shows harvesting schedule for 2017

Year	Compartment	Area (fed)	Operation	Number of stems per Diameter class	Volume to be cut
				5 –7.9	
2017	9	332	Selective felling	1704	221.5
	10	253	Selective felling	5565	723.6
Total				7269	945.1

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. Natural forests in Gdaref State area can be surveyed, mapped and enumerated to provide the needed knowledge about species composition and size-classes profiles of the most useful species to facilitate sustainable development, planning and management. .
2. The relationship between height and diameter at breast height was made for *Acacia seyal*, the results showed a straight-line equation (simple linear regression). The equation to determine the height for Talih trees is h = 3.3526 + 0.2913dbh.
3. An attempt was made to fit form factor equation for Talih trees growing in the study aera , regression techniques were used. To select the best equation for Talih form factor the following equation

   FF = 0.6403 - 0.0056dbh + 0.154h. was used.
4. When harvesting *Acacia seyal*, the selective system is considered the only appropriate system that fulfils the objective of sustained yield based on target diameter for

the intended products in Gadaref State, due to the present state of *Acacia seyal* which is characterized by:

- age gradation is not clear; not attaining a normal structure.
- the selection system:

  (a) enhances environmental stability and ecological balance

  within Gadaref area.

  (b) maintains bio-diversity and provides opportunities for

  eco-tourism.

  (c) reduse the loss of top soil nutrients.

5. Preparation of management plans for the natural forest facilitates rational development and sustainable use of the resources for multiple benefits and end uses.

6.2 Recommendations

1. Natural forests have to be managed on the basis of sustainability and multiple uses.
2. Selective system is recommended to be applied in Gadaref State, because clear felling is hazardous.
3. Site studies to facilitate site mapping on the basis of site characteristics and species suitability.

4. The management of the stands on sustainable basis, Since Gadaref State has valuable natural resources that contain a wide range of commercial species that have a very low cost of production, their utilization on proper sustainable management will enhance Gadaref State economic viability.
5. There is a real need for running successful national inventories for natural forests at defined intervals of time in order to compare the different changes, which may occur. Securing such information facilities leads to proper management decisions and improves the capacity of managing and maintaining natural forest.

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